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WIDEBAND TRANSMISSION THROUGH

NARROWBAND TRANSPONDER

Field of the Invention

This invention relates to
5 communications, and more particularly to
communications of both wideband and narrowband
signals over a communication path including a
beamformer.

Background of the Invention

10 Communications are very important in
the modern world. Techniques for communication
include public switched telephone systems
(PSTNs) operating over land lines, and also
include other types of terrestrial lines, such
15 as microwave links and fiber optic buses. The
increasing use of the Internet makes wideband
communications more important. For many
purposes, land-line communications are not
suitable, as for example for communication to
20 or with aircraft and ships at sea. For
communications with such mobile stations,
conventional ship-to-shore type long-wave
systems are not satisfactory, in that they tend
to be very narrow-band.

Communications satellites or transponders are coming into widespread use for communications with locations which are not served by land lines. Such communications
5 systems include satellite-based mobile telephone systems. These systems include low-earth-orbit (LEO) systems, in which the satellite constellations provide low time latency because of the proximity of the
10 communicating satellite to the earth's surface.

LEO systems have not found favor, because of the complexity of the handover of signal among satellites, and because the large number of satellites required for complete coverage and
15 system economics necessitated inexpensive, and therefore limited-capability satellites. These limited-capability satellites, in turn, have small-aperture antennas and relatively low-power transmitters. These, in turn limit the
20 performance, and tend to make the user terminals or handsets bulky and expensive.

Geosynchronous communications satellites have the advantage of not requiring earth stations to track the spacecraft, since
25 its position relative to a fixed location on the earth's surface remains fixed. Fewer geosynchronous spacecraft are required to provide broad coverage, but complete earth coverage is not possible, or is at least
30 difficult. In an inclined orbit, more coverage is possible, but tracking is required. Geosynchronous orbits are, however, distant

from the earth, and consequently require large-aperture antennas and relatively high transmitted power (EIRP) to provide reliable communications with earth stations and user terminals. Some geosynchronous systems, such as Echostar, are simple "bent-pipe" systems, in which the uplinked signal modulated onto a carrier is merely converted to a different carrier frequency and downlinked, with the change in frequency being for providing isolation between uplink and downlink. Other systems receive uplinked carrier signals modulated with digital signals representing independent information such as an individual mobile user conversation, and actually demodulate the independent signals to baseband and process the digital signals, as for example to regenerate the digital signals to obviate waveform degradation attributable to the uplink.

Improved communications systems are desired.

Summary of the Invention

A communication spacecraft provides cellular communications among a plurality of user terminals and ground stations, by way of paths having a bandwidth generally suited for audio signals, and also provides communications among at least the ground stations by way of at least one path having a bandwidth at least five times greater than the bandwidth suitable for audio signals. The spacecraft includes a

downlink antenna including a plurality of
antenna elements, for receiving guided
electromagnetic energy at a feed port of each
of the antenna elements, and for radiating the
5 energy in the form of unguided radiation. The
spacecraft also includes an analog beamformer
including a plurality of beam input ports and a
plurality of elemental antenna ports, each of
which is coupled to one of the antenna
10 elements, for producing at least one
independent beam of electromagnetic downlink
radiation from guided energy applied to each of
the beam input ports, so that plural downlink
antenna beams are formed when signals are
15 applied to a plurality of the beam input ports
of the analog beamformer. A receiving
arrangement receives unguided electromagnetic
uplink radiation including at least one
carrier, and at least transduces the unguided
20 electromagnetic uplink radiation into guided
electromagnetic energy on a plurality of
separate paths. In some contexts, the
receiving arrangement also downconverts the
signal carrier frequency to a lower frequency
25 or to baseband. A narrowband digital
channelizer has individual channels. Each of
the individual channels has a bandwidth
suitable for audio signals. The channelizer
includes a plurality of input ports and a
30 plurality of output ports. At least some of
the input ports of the digital channelizer are
coupled by way of corresponding ones of the

plurality of separate paths to the receiving arrangement. The digital channelizer receives the guided electromagnetic energy from a plurality of the separate paths, and extracts
5 each of the independent narrowband signals from at least one carrier, to thereby produce separated independent narrowband signals on the plurality of output ports of the digital channelizer. A wideband channelizer has an
10 individual channel bandwidth at least five times greater than that of an individual channel of the narrowband channelizer. The wideband channelizer is coupled to at least a portion of the receiving arrangement, for
15 extracting at least one wideband signal from the carrier, to thereby produce separated independent wideband signals. A switching arrangement is coupled to the plurality of output ports of the narrowband channelizer and
20 is also coupled to the wideband channelizer. The switching arrangement receives the independent narrowband signals and the wideband signals, and groups together those signals associated with each of the plural downlink
25 antenna beams, to thereby produce combined signals grouped by beam. The combined signals grouped by beam may include any number of the wideband signals, including the number zero. Lastly, the spacecraft also includes a coupling
30 arrangement coupled to the switching arrangement and to the corresponding beam input ports of the beamformer. This causes the

beamformer and the downlink antenna to route each of the combined signals to the antenna beam for which it is destined.

A method according to another aspect
5 of the invention is for transmitting wideband signals and at least some of a plurality of independent signals through an analog beamformer. Each of the independent signals has a bandwidth no greater than one-fifth of
10 that of the wideband signals. The method includes the step of receiving unguided electromagnetic radiation including (a) a plurality of the independent signals having bandwidths suitable for audio
15 use and (b) the wideband signals, to thereby produce guided electromagnetic energy signals representing combined wideband signals and narrowband independent channels. In one mode of this method, the plurality of independent
20 signals is modulated onto a subcarrier which is, in turn, modulated onto a carrier. The method according to the aspect of the invention further includes the steps of channelizing the signals representing combined wideband signals
25 and narrowband independent channels, to thereby extract separated independent narrowband signals, and of separately channelizing the signals representing combined wideband signals and narrowband independent channels, to thereby
30 extract separated wideband signals. Those of the separated independent narrowband signals and the separated wideband signals which are

associated or destined for transmission over the same antenna beam are combined so as to produce antenna beam signals. The antenna beam signals are beamformed to produce plural
5 antenna element guided wave signals which, when combined "in space" produce the desired beams.

The last step of the method according to this mode of the method is to couple each of the antenna element guided wave signals to the
10 guided wave input port of one of the antenna elements of an antenna array, so that each one of the antenna element receives one, and only one, of the antenna element guided wave signals. In a particularly advantageous mode
15 of the method according to the invention, the step of channelizing the signals representing combined wideband signals and narrowband independent channels includes the step of digitally channelizing the combined wideband and narrowband independent channels. In a
20 further advantageous mode of the inventive method, the step of channelizing includes the step of limiting the bandwidth of each of the independent signals to a bandwidth suitable for carrying of intelligible audio, which in one
25 version is a bandwidth of less than about 10 Khz.

Brief Description of the Drawing

FIGURE 1 is a simplified block
30 diagram of a portion of a spacecraft including portions of the forward communication system;

FIGURE 2 is a simplified block

diagram of a wideband portion of the structure of FIGURE 1;

FIGURE 3 is a simplified diagram of a spacecraft-based communication system in which
5 the invention may be used;

FIGURE 4 is a simplified block diagram of a portion of a spacecraft including portions of the reverse communication system; and

10 FIGURE 5 is a simplified block diagram of a wideband portion of the structure of FIGURE 4.

Description of the Invention

FIGURE 3 is a simplified block
15 diagram of a spacecraft communication system 8.

In FIGURE 3, a spacecraft 10 includes an uplink antenna 12 and a downlink antenna 30. On the surface 300 of the Earth, a ground station 310 includes an antenna 310A by which
20 ground station 310 communicates with the spacecraft 10. Also illustrated are a plurality of mobile user terminals (UT) illustrated together as 312. User terminals 312 communicate with other user terminals and
25 with the ground station 310 by using the satellite's communication system 11 as a transponder.

In FIGURE 1, a forward portion 11F of a spacecraft communication system 11 includes a
30 set of antennas designated as 12, including antennas 12_a , 12_b , . . . , 12_f . Antenna set 12 represents a set of uplink antennas on a

spacecraft for receiving uplinked signals, as from an earth station. Antenna set 12 may be, for example, a high-gain antenna reflector pointed at an earth station or gateway in the context of a mobile station communications system, with individual feed antenna elements 12_a, 12_b, . . . , 12_f. Uplinked signals are received by the antennas of set 12. More particularly, in the ACeS system, for example, the uplink signal includes plural C-band carriers, and each of the C-band carriers has a bandwidth of about 300 MHz, and is modulated with subcarriers spaced by a bandwidth. In the context of an ACeS system, the subcarrier spacing is about 200 KHz. Each subcarrier, in turn, may be modulated with a number of information signals, such as eight full-rate independent audio information signals (full rate meaning one time-division-multiplex (TDM) burst each frame) or thirty-two quarter-rate independent audio information signals (where quarter-rate means one TDM burst every four frames). In the case of ACeS, the independent TDM signals include cellular telephone signals. Each of the plural (eight or thirty-two) independent signals occupies the 200 KHz bandwidth of its subcarrier exclusively during its portion of the TDM interval or slot.

The signals received by each antenna of set 12 of FIGURE 1 are applied to an associated C-band receiver of a set 14. More specifically, antenna 12_a is coupled to a C-band

receiver (RCVR) 14_a and its associated local
oscillator (LO) 16_a, antenna 12_b is coupled to a
C-band receiver (RCVR) 14_b and its associated
local oscillator (LO) 16_b, . . . , and antenna
5 12_f is coupled to a C-band receiver (RCVR) 14_f
and its associated local oscillator (LO) 16_f.
Each C-band receiver 14_a, 14_b, . . . , 14_f of set
14 is an analog processing device which filters
the received signals to reduce undesired out-
10 of-band signals, and also receives
intermediate-frequency (IF) signals from an
associated synthesized or otherwise stable
local oscillator of a set 16 of local
oscillators. More particularly, a local
15 oscillator 16_a is associated with receiver 14_a,
a local oscillator 16_b is associated with
receiver 14_b, . . . , and a local oscillator 16_f
is associated with receiver 14_f. Thus, there
is, in principle, one receiver of set 14 for
20 each antenna of set 12; the need for redundancy
of active devices may, however, require
additional or supernumerary receivers, and
additional switching (not illustrated) for
switching among the receivers. Each receiver
25 of set 14 has an instantaneous bandwidth of
about 30 MHz, may be tuned across the 300 MHz
bandwidth of a C-band carrier, so as to allow
any one of the receivers of set 14 to access
any one signal, or any group of frequency-
30 adjacent signals having a combined bandwidth of
less than about 30 MHz. This tuning may be
effectuated for any receiver of set 14 by

tuning the IF signals from its associated local oscillator of set. Thus, the output bandwidth of any C-band receiver 14 represents any desired 30 MHz portion of the 300 MHz C-band bandwidth. Each receiver of set 14 downconverts its selected 30 MHz band to an intermediate frequency (IF). In the case of ACeS, the intermediate frequency is around 400 MHz.

The downconverted 30 MHz band associated with any particular receiver 14_a, 14_b, . . . , 14_F of set 14 is applied to a corresponding analog forward link downconverter. More particularly, the downconverted 30 MHz band of signals from receiver 14_a of FIGURE 1 is applied to an analog forward link downconverter (FLD) block 18₁, which represents downconversion from the IF frequency to baseband, the downconverted 30 MHz band of signals from receiver 14_b of FIGURE 1 is applied to an analog forward link downconverter (FLD) block 18₂, which represents downconversion from the IF frequency to baseband, . . . , and the downconverted 30 MHz band of signals from receiver 14_F is applied to an analog forward link downconverter block 18_F. It should be understood that the number of FLD blocks equals the number of C-band receiver blocks in principle, but again the requirements for reliability redundancy may require more of one than of the other. Thus, each receiver of set 14 of receivers produces output signal having a

bandwidth no greater than about 30 MHz,
modulated onto an intermediate-frequency (IF)
carrier. The signals produced at the output
ports of the C-band receivers of set 14 are
5 ultimately coupled to a block 20, which
represents a digital channelizer. Because it
is easier at the current state of the art to
make a digital channelizer which operates at
baseband rather than at an IF frequency, it is
10 desirable to downconvert each of the IF-based
signals, as produced by the C-band receivers of
set 14, to baseband. Conversion to baseband of
the IF-frequency signals produced at the output
of each C-band receiver of set 14 is performed
15 by a corresponding one of the forward link
downconverters (FLDs) of a set 18. More
particularly, a forward link downconverter 18_1
is associated with C-band receiver 14_a , a
forward link downconverter 18_2 is associated
20 with C-band receiver 14_b , . . . , and a forward
link downconverter 18_f is associated with C-band
receiver 14_f . The only reason for the use of
the set 18 of FLDs, then, is due to the
economics of fabrication of the digital
25 channelizer 20, and the combination of the
downconverters of set 18 and the digital
channelizer 20 may be considered to be simply a
digital channelizer 21, since there is no
requirement in principle for downconversion to
30 baseband. As illustrated in FIGURE 1,
channelizer 20 has FLDs of set 18 coupled to
its input ports $20i_1$ through $20i_N$. More

particularly, channelizer 20 has its input port
20i₁ coupled to receive signal from FLD 18₁, its
input port 20i₂ coupled to receive signal from
FLD 18₂, . . . , and its input port 20i_N coupled
5 to receive signal from FLD 18_N. Channelizer 20
has about 140 active output ports in the ACeS
version, and additional ports for
redundancy/reliability and for additional
capacity under certain circumstances. Thus,
10 channelized digital signals are available at
each of the output ports 20o₁, 20o₂, . . . ,
20o₁₄₀ of channelizer 20, regardless of whether
FLDs are used or not. The digital signals
produced at each output port 20o₁, 20o₂, . . . ,
15 20o₁₄₀ of channelizer 20 are in the form of
digital signals modulated onto a baseband
carrier, and each such modulated baseband
carrier represents a plurality of independent
digital signals, with each independent signal
20 representing, for example, voice signal
travelling in one direction to or from a mobile
user terminal on the ground. In practice,
channelizer 20 has an ultimate bandwidth of
about 9 MHz per beam output port, which
25 translates to about 45 subcarriers,
corresponding to a maximum of 280 full-rate
audio channels, or about a thousand quarter-
rate audio channels per output port. It should
be noted that each active output port 20o₁,
30 20o₂, . . . , 20o₁₄₀ represents one antenna beam,
so if, as in the case of ACeS, there are 140
outputs from the digital channelizer, 140

separate antenna beams are intended.

The output ports of channelizer 20 of
FIGURE 1 are coupled to a switch matrix
illustrated as 22. Switch matrix 22 is a
5 digitally-controlled analog-signal-handling
device, which couples the digital-modulated-
onto-carrier signals from each output port $20o_1$,
 $20o_2$, . . . , $20o_{140}$ of channelizer 20 to one of a
set 24 of active forward link upconverters
10 (FLUs), which are designated 24_a , 24_b , . . . ,
 24_{140} . The ACeS spacecraft uses about 140
active FLUs, and has a total of about 180 FLUs,
with the inactive FLUs being spares for
redundancy. Each FLU 24_a , 24_b , . . . , 24_{140} of
15 set 24, with the aid of an associated local
oscillator (LO), upconverts the digital-
modulated-onto-carrier combined independent
signals applied thereto from an output port of
channelizer 20. The frequency upconversion is
20 to a downlink frequency, which in the case of
ACeS happens to be at about 1500 MHz. The
resulting upconverted signals (at a downlink
frequency) produced at the output of each FLU
of set 24 are coupled from the FLU to a
25 corresponding input port of a switch combining
matrix (SCM) 26. SCM 26 has a total of about
180 input ports, and about 140 output ports.
Each of the 140 output ports of SCM 26 is
coupled by way of a path of a coupling
30 arrangement 27 to one of the beam input ports
 $28i_1$, $28i_2$, . . . , $28i_{140}$ of a beamformer 28.
More particularly, output port $26o_1$ of SCM 26 is

coupled by way of signal path 27_1 to input port $28i_1$ of beamformer 28, output port $26o_2$ of SCM 26 is coupled by way of signal path 27_2 to input port $28i_2$ of beamformer 28, . . . , and output
5 port $26o_{140}$ of SCM 26 is coupled by way of signal path 27_{140} to input port $28i_{140}$ of beamformer 28. SCM 26 is basically a switch matrix which allows the signals from any combination of 140 active FLUs to be coupled to
10 a beam input port of beamformer 28, and which also allows the output signals of two or more FLUs to be coupled (through hybrids) to a single beam input port of the beamformer. The switching function allows failed FLUs to be
15 replaced by functional FLUs, and the switching-plus-combining function also allows for additional functionality of increasing the beam capacity under circumstances where a particular antenna beam experiences particularly high
20 traffic during a period of time. For purposes of understanding the principles of the invention, SCM 26 may be ignored.

In general, the signals from each FLU $24_a, 24_b, . . . , 24_{140}$ of set 24 are applied to
25 one corresponding beam input port $28_1, 28_2, . . . , 28_{140}$ of beamformer 28. As known to those skilled in the art, the beamformer couples the signals applied to each beam input port $28_1, 28_2, . . . , 28_{140}$ to the guided-electromagnetic-
30 wave input ports $30i_a, 30i_b, . . . , 30i_M$ those antenna elements $30_a, 30_b, . . . , 30_M$ of antenna set 30 as necessary to form an antenna beam of

the desired type and shape. In the ACeS system, there are about 140 spot beams. The independent signals destined for each beam are coupled from the beam input port of beamformer
5 28 to the corresponding downlink antenna beam, and in general not to the other beams.

As so far described, the structure of system 10 of FIGURE 1 is a part of a system designated RHC, which stands for Right-Hand-
10 Circular. This designation refers to the polarization of the uplink antenna set 12. As known to those skilled in the art, another set 112 of antennas, similar to set 12, but of the other hand of polarization, may be used in
15 conjunction with set 12. This other hand of polarization is termed left-hand-circular (LHC). In principle, it is possible to use the same uplink frequencies with the other hand of orthogonal polarization in order to re-use the
20 frequency band. Thus, independent signals can in principle be received by the set of antennas designated 112 in the LHC section of the system 10. Each antenna 112_a through 112_r of set 112 is coupled to a corresponding C-band receiver
25 114_a, . . . , 114_o of a set 114 of C-band receivers. As in the case of the RHC portion of the system, the C-band receivers are coupled to FLDs 118₁, . . . , 118_o of a set 118 of FLDs.

The outputs of the FLDs of set 118 are applied
30 individually to the input ports 20i_a, . . . , 20i_o of digital channelizer 20. The various C-band receivers of set 114 and FLDs of set 118

perform in a manner equivalent to those of sets
14 and 18, with the only difference being in
the signals handled, as the antennas of set 112
are capable of receiving signals of a different
5 set from those received by antenna set 12.

According to an aspect of the
invention, one or more wideband transmission
paths is provided between the C-band receivers
14a, 14b, . . . , 14N of set 14 and beamformer
10 28, so that wideband signals, such as Internet
signals, can flow through the spacecraft
portion of the communications link. More
particularly, the wideband transmission path
bypasses the narrowband part of the spacecraft
15 communications channel, which is the digital
channelizer 20. Since, as mentioned, the
channelizer may be viewed as including the
associated FLDs of set 18, the wideband
transmission path can also be routed around or
20 bypass the FLDs. In the arrangement of FIGURE
1, a forward-direction wideband augmentation
equipment (FWAE) 32 is illustrated as providing
a path which bypasses FLD 18₁ and digital
channelizer 20. More particularly, the signal
25 path between C-band receiver 14_a and FLD 18₁ is
illustrated as including a power splitter or
signal bypass 17. FWAE 32 is illustrated as
having its input port 32i coupled by way of a
signal path 17p to an output port of splitter
30 17, for receiving a sample of the signal
received by C-band receiver 14_a. FWAE 32
processes the signal sample by at least

downconverting the signal, with the aid of its own LO, to a frequency corresponding to that at the outputs $20o_1$, $20o_2$, . . . , $20o_{140}$. The frequency-converted wideband signals produced at the output of FWAE 32 are coupled by way of a signal path 32p to an input of switch matrix 22, where the signals can be processed in a wideband manner. All locations downstream from switch matrix 22, namely the FLU set 24, the SCM 26, and the beamformer 28, are capable of wideband operation, so a path is provided by which broadband signals can be processed through a spacecraft fitted for mobile user terminal communications. This, in turn, allows a spacecraft fitted for mobile user terminal communications, which are ordinarily narrow-band, to handle wideband signals such as Internet communications.

The invention is not limited to providing a single wideband forward signal path through the spacecraft. As illustrated in FIGURE 1, a further signal sampler 117 is illustrated as being coupled to the signal path extending between C-band receiver 114_o and FLD 118_o. The sampled signal is illustrated as being coupled to a further forward wideband augmentation equipment 132, which processes the signals in its path in the same manner as those processed in FWAE 32, and applies the wideband signals so processed to another input port of switch matrix 22. In a similar manner, other FWAEs, such as 32', can be coupled to other

signal samplers, such as 17', and to other input ports of switch matrix 22. It should be understood that, in general, wideband signals and narrowband signals should not appear at the same frequencies at the outputs of the various C-band receivers, but that, if such should occur, the signals in the overlap bands may be required not to appear in the same beams, as their presence in the same beams may be associated with different group delays and phases, and as such may interfere.

FIGURE 2 is a simplified block diagram of one possible implementation of forward wideband augmentation equipment 32. In FIGURE 2, elements corresponding to those of FIGURE 1 are designated by the same reference numerals. In FIGURE 2, the wideband RHC polarization, downconverted signal samples of the signal produced by C-band receiver 14_a of FIGURE 1 are coupled over signal path 17p to FWAE 32. Within FWAE 32, the signals are applied in common or in parallel to a bank 232 of filters. While the number of filters may be almost arbitrarily selected, the illustrated arrangement includes three filters 232_{0.5}, 232_{1.0}, and 232_{2.0}, which have passbands with a width of 0.5, 1.0, and 2.0 MHz, respectively. Such filters are well known in the art, and require no further explanation. Because of their light weight, surface-acoustic-wave (SAW) filters are particularly advantageous for spacecraft use. Wideband signals with various bandwidths are

available at the output ports of the filters of filter bank 232. The variously filtered signals are applied to a switch bank 210, illustrated as containing a bank of

5 controllable switches, which allow the signals from one or more of the filters $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$ to be coupled to an input port 212i of a downconverter 212. The filter passbands can be so arranged that the total bandwidth of
10 the filter bank can be summed. For example, when filter $232_{0.5}$ (which has a bandwidth of 0.5 MHz) is connected to the 212 downconverter via the 210 switch concurrently with filter $232_{1.0}$ (which has a bandwidth of 1.0 MHz), the total
15 effective bandwidth of the filtering applied to the input of the 212 downconverter is the sum of 0.5 MHz and 1.0 MHz, or 1.5 Hz. The downconverter downconverts the selected wideband signal and makes it available on
20 signal path 32p for application to an input port of switch matrix 22 of FIGURE 1. The wideband signal is then propagated, together with narrowband signals from digital channelizer 20, through wideband portions of
25 the structure of FIGURE 1, including the switch matrix 22, FLU bank or set 24, SCM 26, and beamformer 28. Thus, the wideband signals can be routed to any of the antenna beams, just as the narrowband signals are routed.

30 FIGURE 4 is a simplified block diagram of a return or reverse portion 11R of the spacecraft 10 communication system. In

FIGURE 4, elements corresponding to those of
FIGURE 1 are designated by like reference
numbers, and elements which are similar but not
identical may be designated by the same
5 reference numerals in the 400 series. In

FIGURE 4, an uplink receive antenna 430
receives uplink signals which may include both
wideband and narrowband portions, but which are
at L-band. The beamformer 428 is similar to
10 beamformer 28 of FIGURE 1, but is a separate
and different unit because the antennas 30, 430
and the operating frequencies are different.
The beamformer 428 forms the beams as described
in conjunction with beamformer 28, and produces
15 at its output port set 4280 groups of signals
representing the uplinked signals on each beam.

These beam-grouped signals are applied to a
switch combining matrix 426, which operates at
a different frequency than does matrix 26 of
20 FIGURE 1. Switch combining matrix 426 performs
redundancy switching of the return or reverse
link downconverters (RLDs) of set 424 of RLDs.

It also provides for channel capacity
augmentation by routing or distributing
25 "excess" signals in one uplink beam to or among
the channelizer inputs. The return link
downconverters of set 424 couple baseband
signals, separated or maintained independent by
the TDM switching, to the switch matrix 22,
30 which can be identical to that of FIGURE 1
because both operate at baseband. While it can
be identical, it cannot be the self-same unit,

because the routing of the signals in the forward direction is not the same as the routing in the reverse direction. The structure of switch matrix 22 is wideband, so there is no particular reason that wideband signals could not be routed to the input ports of channelizer, nor is there any reason that narrowband signals could not be routed to path 32p, although this would be undesirable, as the wideband signals if applied to a channelizer input port would be rendered narrowband and likely useless, and narrowband signals if applied to the wideband signal paths would not take advantage of the available bandwidth. Ordinarily, the narrowband signals will be routed to the input ports $20i_1$, $20i_2$, . . . , $20i_{140}$ of channelizer 20, and the wideband signals, if any are present, will be routed to the wideband augmentation equipment 432. In general, digital channelizer 20 of FIGURES 1 and 4 operate at baseband, and so can be structurally identical (although the self-same units cannot be used because the routing of signals in the forward and reverse directions differs). The wideband augmentation equipment 432 is similar, but not identical to, the corresponding equipment 32 of FIGURE 1. The major difference between the two wideband augmentation equipments is that the forward-direction wideband augmentation equipment 32 receives input signals at about 400 MHz for proper operation of the SAW filters, and then

downconverts to baseband, while the reverse-
direction wideband augmentation equipment 432
of FIGURE 4 receives baseband signals, and must
upconvert the baseband signals to a range
5 suitable for operation of the SAW filters.

Channelizer 20 of FIGURE 4 produces
narrowband signals destined for RHCP
transmissions on a set $20o_1, 20o, \dots, 20o_N$,
which are grouped by gateway destination, are
10 routed through a set 418 of return link
upconverters (RLU), for conversion to an IF
frequency in the range of 400 MHz. The
upconverted signals at the outputs of RLUs of
set 418 are applied to C-band transmitters of a
15 set 414, which upconvert the IF signals to the
C-band downlink frequencies, in the vicinity of
3.4 GHz. The transmit signals are applied from
the C-band transmitters to the antenna elements
of an antenna 412 which is different from
20 antenna 12 of FIGURE 1 because of operating
frequencies, but is functionally identical.

Similarly, the narrowband output
signals destined for the LHCP downlink are
produced at output ports $20o_a, \dots, 20o_o$ of
25 channelizer 20 of FIGURE 1, and are coupled to
their respective reverse link upconverters of
set 418, thence to the corresponding C-band
transmitters of set 414 and on to the RHCP
antennas. The wideband signals coupled through
30 return wideband augmentation equipment 432 is
applied through a signal sampler or directional
coupler 17, which is identical to that of

FIGURE 1, to thereby couple the wideband signals to one of the C-band transmitters. The simplified illustration allows the wideband signals to be transmitted to only a few of the ground stations, but in an actual unit, a switch matrix might be used to route the wideband signals to any of the C-band transmitters of set 14, or a plurality of return wideband augmentation equipments corresponding to 432 could be provided, together with a signal sampler or directional coupler corresponding to 17 providing access to each of the C-band transmitters of set 414. Also in FIGURE 4, switch matrix 22 couples wideband signals to additional return wideband augmentation equipments 432 and 432'', which operate much like equipment 432, and which couple their wideband output signals to signal samplers or directional couplers 17' and 117, respectively.

FIGURE 5 is a simplified block diagram illustrating details of return wideband augmentation equipment 432 of FIGURE 4. In FIGURE 5, the wideband baseband signal from switch matrix 22 of FIGURE 4 is applied over signal path 32P to an upconverter 512 of return wideband augmentation equipment 432. Upconverter 512 upconverts the signal to a frequency in the range of about 400 MHz, which is suitable for operation of SAW filters. The upconverted wideband return signal is applied to a common portion of a switch matrix

illustrated as 510, which selects one of a plurality of possible signal paths for the upconverted return signal from upconverter 512. Each path selectable by switch matrix 510 leads to a SAW filter. As in the case of FIGURE 2, the SAW filters are designated $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$, which have passbands with a width of 0.5, 1.0, and 2.0 MHz, respectively. The return signal, filtered by the selected one or more of SAW filters $232_{0.5}$, $232_{1.0}$, and $232_{2.0}$, is coupled by way of signal path 432' to signal sampler or directional coupler 17 of FIGURE 4. The filter passbands are so arranged that the total bandwidth of the filter bank can be summed. For example, when filter $232_{0.5}$ (which has a bandwidth of 0.5 MHz) is connected to the 512 upconverter via the 510 switch concurrently with filter $232_{1.0}$ (which has a bandwidth of 1.0 MHz), the total effective bandwidth of the filtering available at the output of the 512 upconverter is the sum of 0.5 MHz and 1.0 MHz, or 1.5 MHz. The other return wideband augmentation equipments of FIGURE 4 are similar to return wideband augmentation equipment 432.

It is worth noting that an "antenna" as used herein refers to a transducer which transduces electromagnetic energy or power bidirectionally (in either direction) between unguided or free-space propagation and guided propagation in a transmission line. An antenna is a reciprocal device, which operates in the same manner in both transmission and reception

modes of operation. For historical reasons,
some of the terms used in antenna practice are
not as descriptive as might be desirable. For
example, the guided-wave port of an antenna is
5 often called a "feed" port, regardless of
whether the antenna is operated in a
transmitting or receiving mode. Similarly, an
antenna "beam" is relatively easy to understand
conceptually when the antenna is operated in a
10 transmitting mode, but the amplitude-versus-
angle characteristics of an antenna operating
in the receive mode are the same as those of an
antenna in the transmitting mode, and so the
term "beam" is also associated with a receiving
15 antenna, even though there is no conceptual
beam involved. Those skilled in the antenna
arts also realize that an antenna never
exhibits perfect polarization purity, in that
an antenna which is nominally RHC will respond
20 to LHC signals, and vice versa, a "vertically"
polarized signal need not be vertical in
orientation nor "horizontally" polarized
horizontal, and a linearly polarized antenna
responds strongly to circularly polarized
25 signals and vice versa.

The use of the term "between" as used
in the description of antenna usage, and as
used in electrical parlance, is different from
the dictionary usage, and in no wise relates to
30 physical location. Generally, the word
"between" as used in electrical applications
means that the origin of the signal or

electrical fields is one of the stated locations or blocks, and the sink or destination of the signal (or fields) is the other one of the stated locations or blocks.
5 The route taken by the signals (or fields) in flowing from source to destination is irrelevant in the electrical context. A similar distinction must be made for electrical usage for the term "parallel," which does not
10 have to do with physical parallelism. Rather, "parallel" in an electrical context refers to the number or existence of multiple paths extending "between" a source and destination.

While switch symbols representing
15 mechanical switch elements have been illustrated, those skilled in the art know that these are merely symbolic or conventional representations, and that in actual practice, mechanical switches are seldom used. Instead,
20 the symbols represent the switching function rather than the device, and the switching function is ordinarily accomplished by semiconductor or solid-state switches, often remotely controllable or controlled.

25 Other embodiments of the invention will be apparent to those skilled in the art. While the particular described embodiment represents an ACeS system, the frequencies and bandwidths may be widely varied from the
30 examples. For example, while the described system is at C-band, those skilled in the art will recognize that the invention is applicable

to other frequency bands, including L, X, and K
bands. Similarly, the various bandwidths of
300 MHZ, 30 MHz, 200 KHz, and the like may be
almost arbitrarily selected, depending upon the
5 characteristics of the system and of the
signals being carried. While the antenna sets
12, 112 of FIGURE 1 have been described as the
feed antennas of a high-gain reflector element,
they may also be viewed as the output ports of
10 the beamformer of a receive antenna array
making a single beam or multiple beams. While
the described transponder is in a spacecraft,
the transponder could as well be terrestrial.
While the routing of the various narrowband and
15 wideband signals has been described in FIGURE 1
as being to an antenna beam, those skilled in
the art know that a given signal may be routed
to more than one antenna beam, and one or more
signals may be routed in a "broadcast" mode so
20 that they are transmitted over all the
available antenna beams. While SAW filters
have been described, other types of filters can
be used if desired.

Thus, a communication spacecraft (10)
25 provides cellular communications among a
plurality of user terminals (312) and ground
stations (310), by way of paths having a
bandwidth generally suited for audio signals,
and also provides communications among at least
30 the ground stations (310) by way of at least
one path having a bandwidth at least five times
greater than the bandwidth suitable for audio

signals. The spacecraft (10) comprises a
downlink antenna (30) including a plurality of
antenna elements (30_a, 30_b, . . . , 30_M), for
receiving guided electromagnetic energy at a
5 feed port (30i_a, 30i_b, . . . , 30i_M) of each of
the antenna elements (30_a, 30_b, . . . , 30_M), and
for radiating the energy in the form of
unguided radiation. The spacecraft also
includes an analog beamformer (28) including a
10 plurality of beam input ports (28i₁, 28i₂, . .
. . , 28i₁₄₀) and a plurality of elemental antenna
ports, each of which is coupled (by way of a
corresponding antenna element feed port 30i_a,
30i_b, . . . , 30i_M) to one of the antenna
15 elements (30_a, 30_b, . . . , 30_M), for producing
at least one independent beam of
electromagnetic downlink radiation from guided
energy applied to each of the beam input ports
(30i_a, 30i_b, . . . , 30i_M), so that plural
20 downlink antenna beams are formed when signals
are applied to a plurality of the beam input
ports (28i₁, 28i₂, . . . , 28i₁₄₀) of the analog
beamformer (28). A receiving arrangement
(12,14) receives unguided electromagnetic
25 uplink radiation including at least one
carrier, and at least transduces the unguided
electromagnetic uplink radiation into guided
electromagnetic energy on a plurality of
separate paths (15_a, 15_b, . . . , 15_P). In some
30 contexts, the receiving arrangement (12, 14)
also downconverts the signal carrier frequency
to a lower frequency or to baseband. A

5 narrowband digital channelizer (18,20; 20) has individual channels. Each of the individual channels has a bandwidth suitable for audio signals. The channelizer (18,20;20) includes a plurality of input ports (18i₁, 18i₂, . . . , 18i_N; 20i₁, 20i₂, . . . , 20i_N, 20i_a, . . . , 20i_o) and a plurality of output ports (20o₁, 20o₂, . . . , 20o₁₄₀). At least some (18i₁, 18i₂, . . . , 18i_N; 20i₁, 20i₂, . . . , 20i_N) of the input ports (18i₁, 18i₂, . . . , 18i_N; 20i₁, 20i₂, . . . , 20i_N, 20i_a, . . . , 20i_o) of the digital channelizer (20) are coupled by way of corresponding ones of the plurality of separate paths (15_a, 15_b, . . . , 15_F) to the receiving arrangement (12,14).
15 The digital channelizer (20 receives the guided electromagnetic energy from a plurality of the separate paths (15_a, 15_b, . . . , 15_F), and extracts each of the independent narrowband signals from the at least one carrier, to
20 thereby produce separated independent narrowband signals on the plurality of output ports (20o₁, 20o₂, . . . , 20o₁₄₀) of the digital channelizer (20). A wideband channelizer (32) has an individual channel bandwidth at least
25 five times greater than that of an individual channel of the narrowband channelizer (20). The wideband channelizer (32) is coupled to at least a portion (14_a) of the receiving arrangement (12,14), for extracting at least
30 one wideband signal from the carrier, to thereby produce separated independent wideband signals. A switching arrangement (26) is

coupled to the plurality of output ports ($20o_1$, $20o_2$, . . . , $20o_{140}$) of the narrowband channelizer (20) and is also coupled to the wideband channelizer (32). The switching arrangement (26) receives the independent narrowband signals and the wideband signals, and groups together those signals associated with each of the plural downlink antenna beams, to thereby produce combined signals grouped by beam. The combined signals grouped by beam may include any number of the wideband signals, including the number zero. Lastly, the spacecraft (10) also includes a coupling arrangement (27) coupled to the (output ports of the) switching arrangement (26) and to the corresponding beam input ports of the beamformer (28). This causes the beamformer and the downlink antenna to route each of the combined signals to the antenna beam for which it is destined.

A method according to another aspect of the invention is for transmitting wideband signals and at least some of a plurality of independent signals through an analog beamformer (28). Each of the independent signals has a bandwidth no greater than one-fifth of that of the wideband signals. The method includes the step of receiving (at receivers of set 14) unguided electromagnetic radiation including (a) a plurality of the independent signals having bandwidths suitable for audio use and (b) the

wideband signals, to thereby produce guided
electromagnetic energy signals (on set 15 of
paths) representing combined wideband signals
and narrowband independent channels. In one
5 mode of this method, the plurality of
independent signals is modulated onto a
subcarrier (200 Khz separation in the example)
which is, in turn, modulated onto a carrier
(one of plural C-band carriers). The method
10 according to the aspect of the invention
further includes the steps of channelizing (20)
the signals representing combined wideband
signals and narrowband independent channels, to
thereby extract separated independent
15 narrowband signals, and of separately
channelizing (32) the signals representing
combined wideband signals and narrowband
independent channels, to thereby extract
separated wideband signals. Those of the
20 separated independent narrowband signals and
the separated wideband signals which are
associated or destined for transmission over
the same antenna beam are combined (26) so as
to produce antenna beam signals. The antenna
25 beam signals are beamformed (28) to produce
plural antenna element guided wave signals
which, when combined "in space" produce the
desired beams. The last step of the method
according to this mode of the method is to
30 couple each of the antenna element guided wave
signals to the guided wave input port of one of
the antenna elements of an antenna array (30),

so that each one of the antenna element
receives one, and only one, of the antenna
element guided wave signals. In a particularly
advantageous mode of the method according to
5 the invention, the step of channelizing the
signals representing combined wideband signals
and narrowband independent channels includes
the step of digitally channelizing the combined
wideband and narrowband independent channels.
10 In a further advantageous mode of the inventive
method, the step of channelizing includes the
step of limiting the bandwidth of each of the
independent signals to a bandwidth suitable for
carrying of intelligible audio, which in one
15 version is a bandwidth of less than about
10Khz.